Superconducting Accelerator R&D Group: Status of ERL and eCooling R&D

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Collider-Accelerator Department

Superconducting Accelerator & eCooling Group

- Mission: Develop SRF accelerator science and technology and electron cooling of RHIC. Projects include:
  - SRF components for electron cooling, RHIC and eRHIC.
    - High-current ERL accelerating cavity
    - High-current SRF electron gun
    - Laser photocathodes for long life and high quantum efficiency.
    - 56 MHz SRF RHIC Storage Cavity
    - Polarized SRF electron gun
    - Crab cavity
  - Construction of Energy Recovery Linac (ERL) at 20 MeV, 0.5 ampere.
  - Electron cooling R&D
    - High-Energy electron cooling
    - Coherent Electron Cooling
    - RHIC “Low Energy” electron cooling

Organizational Chart

- (I. Ben-Zvi), GL
- (V. Litvinenko), Deputy
- (P. Manning), Secretary
- A. Burrill
- R. Calaga
- X. Chang
- E. Choi
- A. Fedotov
- H. Hahn
- D. Kayran
- J. Kewisch
- (G. McIntyre)
- D. Naik
- D. Pate
- (E. Pozdeyev)
- G. Wang
- Q. Wu

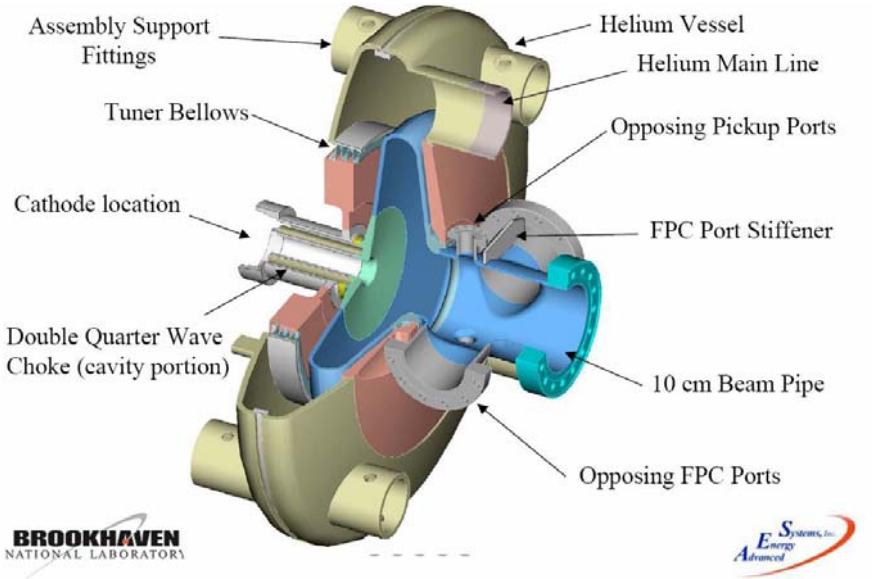
Outstanding support from all of C-AD groups is acknowledged.

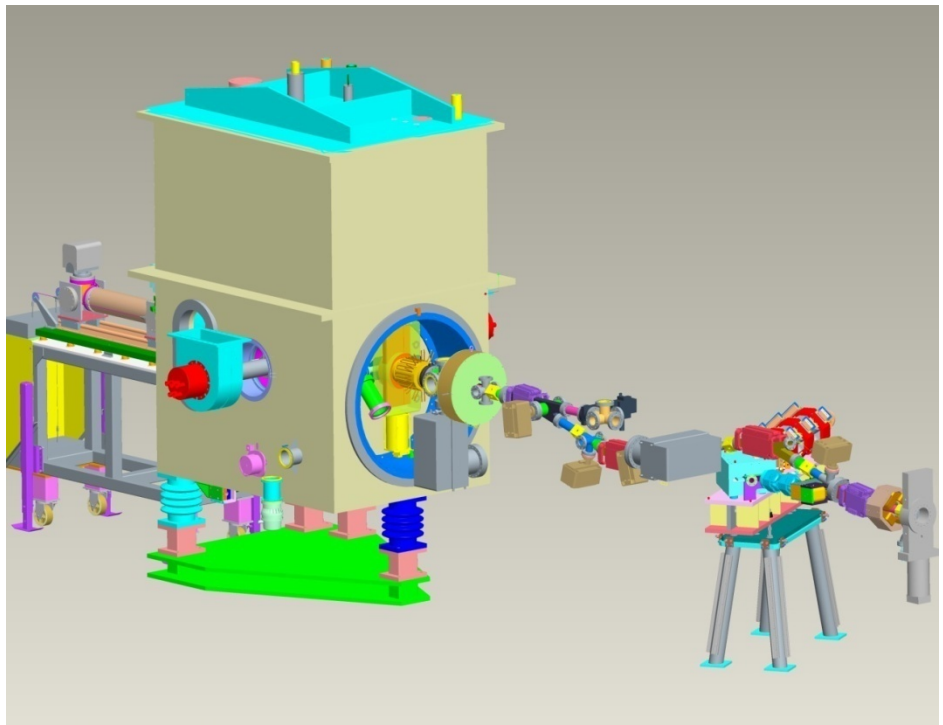
Also – T. Rao and J. Smedley, Instrumentation Division

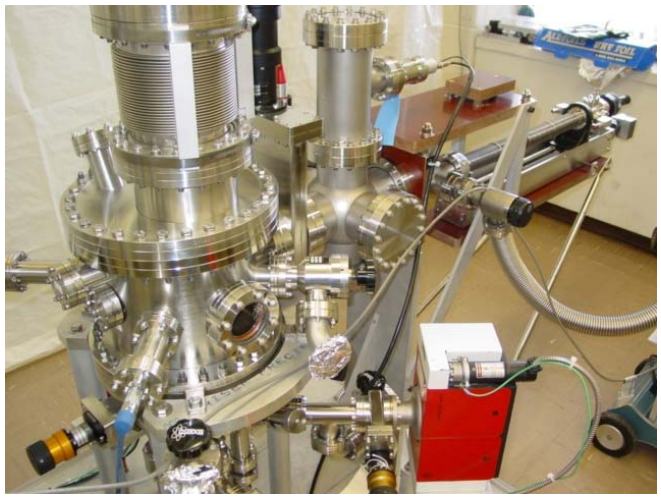
The status of SRF Accelerator R&D

- ERL R&D is aimed at eRHIC - both for the 20 GeV electron accelerator and for Coherent Electron Cooling – but with possibly substantial benefits also for RHIC luminosities.
- 5-cell high-current cavity successfully tested vertically, horizontal test at BNL in 2008
- SRF electron gun is under construction.
- R&D funding leveraging: Navy added last year $1.8M and this year $1.35M direct to project.
- 56 MHz cavity is in advanced design stage – details in presentation of Eunmi Choi.
- Other SRF Accelerator projects are the polarized electron SRF gun (LDRD funding) and crab cavity R&D (LARP funding)

2 MeV, 0.5 A electron gun







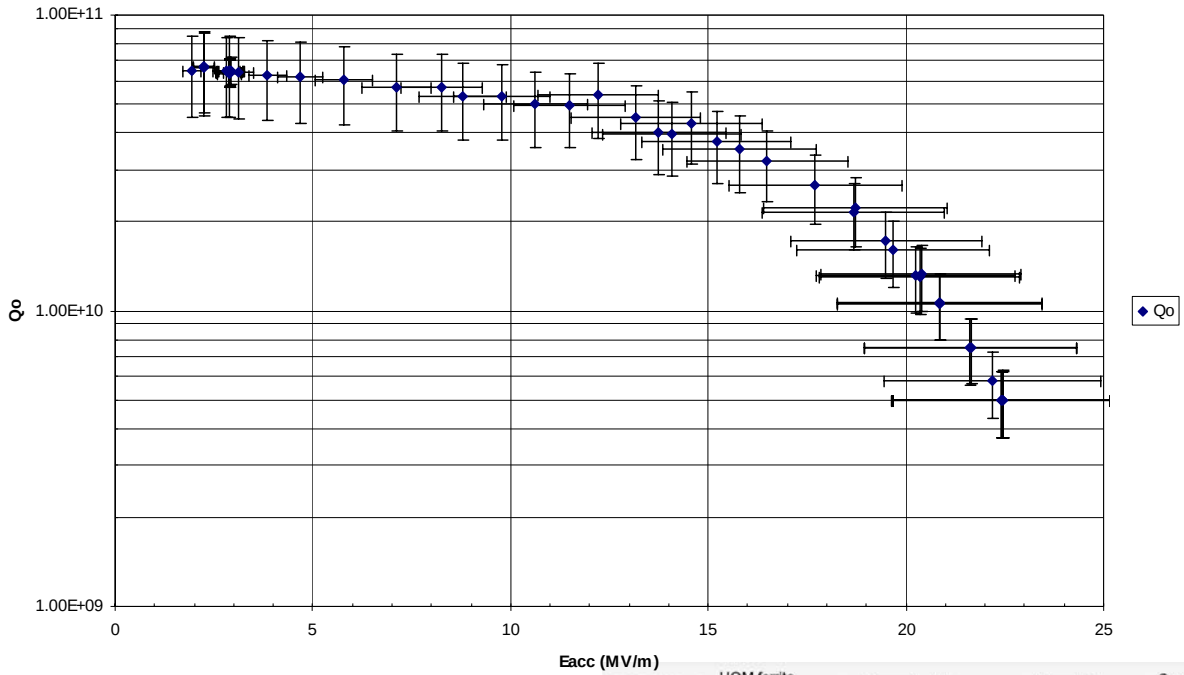
High-brightness, high current electron gun.
Z-bend beam merging system.
Photocathode R&D.

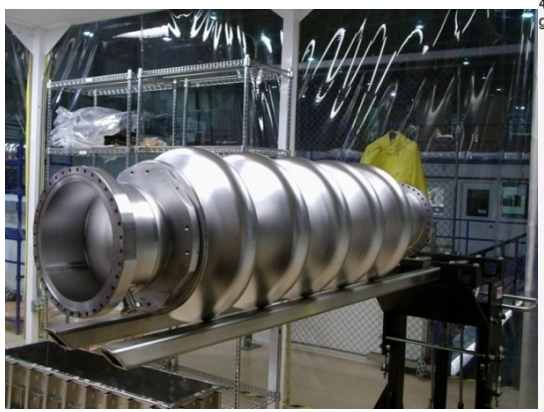
Multi-ampere ERL cavity

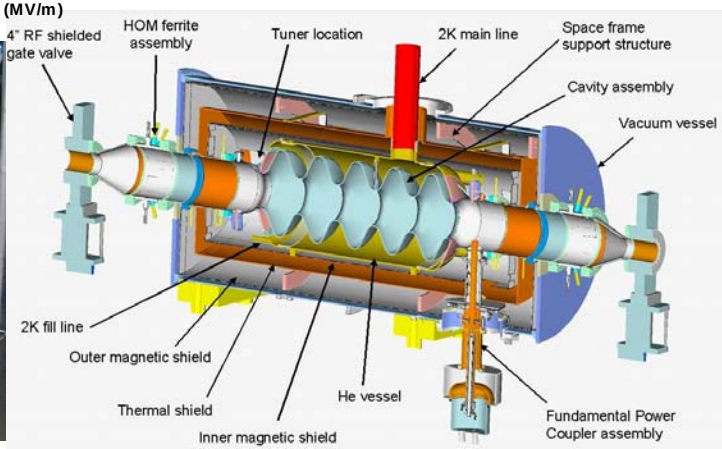
“Single mode” cavity.
$Q > 10^{10}$

@20 MV/m CW

JLab measurement



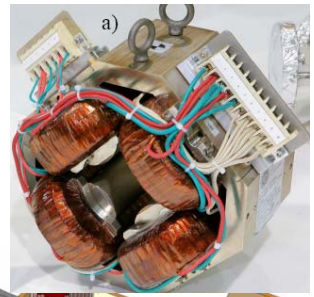


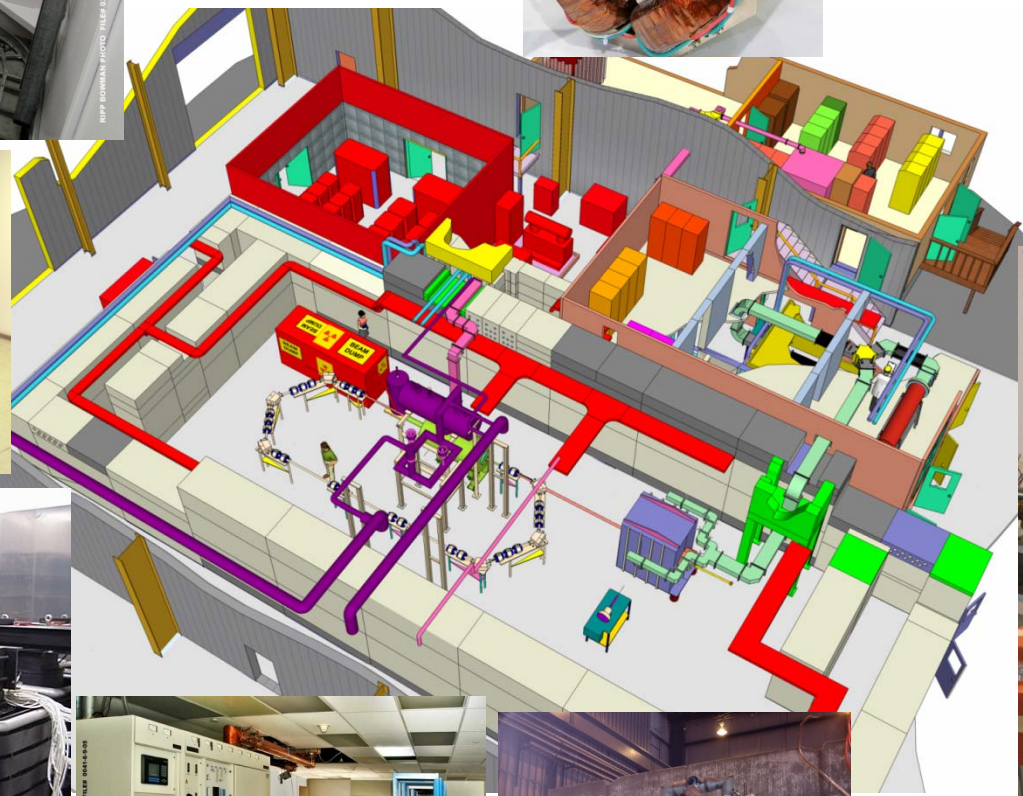


Status of ERL

- 1 MW klystron installed, undergoing acceptance test
- Photocathode preparation chamber delivered
- Laser to be delivered 2008
- Many components fabricated
- Most of magnetic measurements has been completed
- Beam test of gun + cavity in 2009
- Beam in ERL 2010-2011
- Test of coherent electron cooling at RHIC 2012-2014

R&D Energy Recovery Linac





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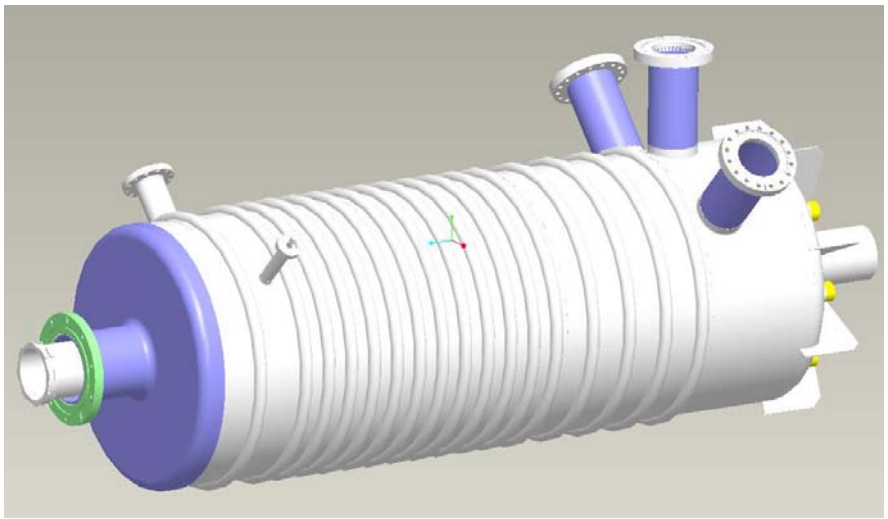
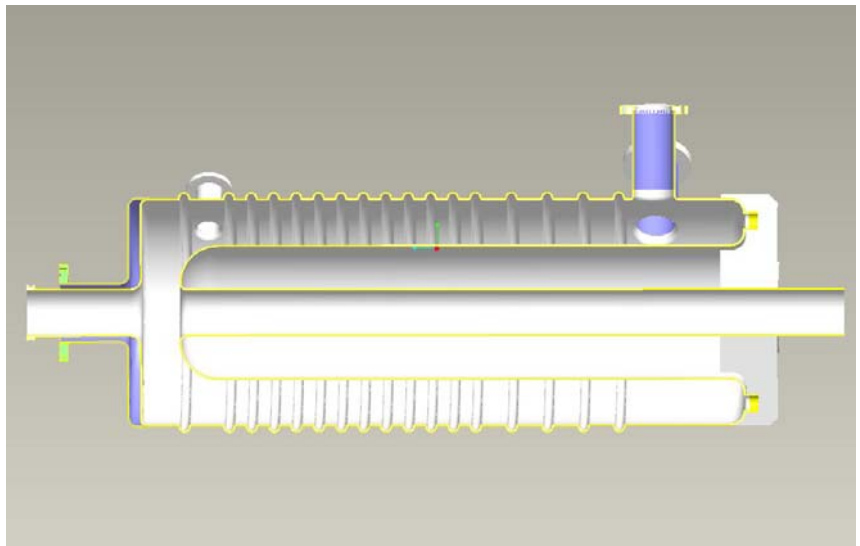
U.S. DEPARTMENT OF ENERGY

56 MHz SRF Storage Cavity for RHIC



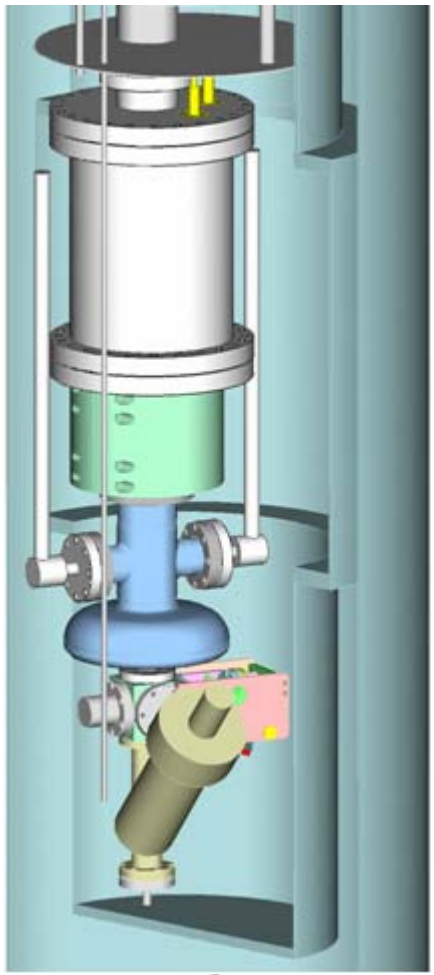
Reentrant cavity geometry with beam Along the cavity axis.
Prevent beam loss from bucket.
Up to 2.5 MV on gap.
Corrugations to prevent multipacting.
Cavity placed in common section, serve both RHIC rings.

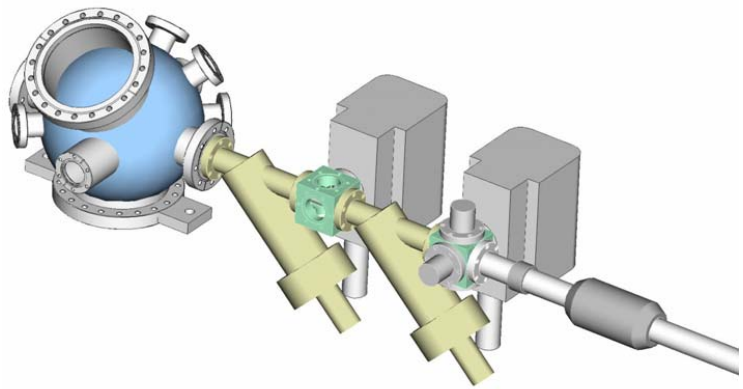
Prevent beam loss from bucket
Allow adiabatic capture –
improve longitudinal emittance.
Result: Double luminosity in vertex.

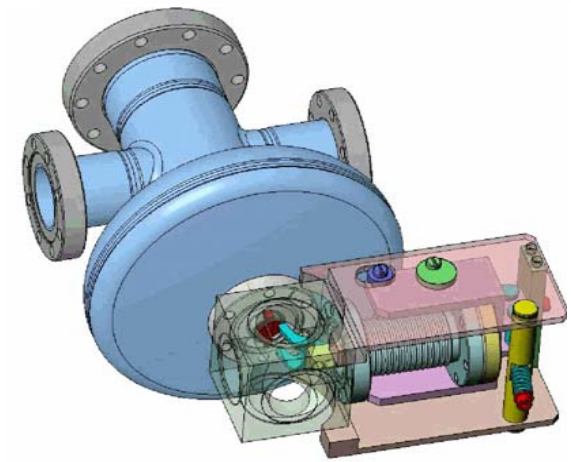


Polarized electron SRF gun R&D

Proof-of-principle for SRF based polarized electron gun.
Potential applications:
ILC – eliminate electron damping ring – huge saving!
eRHIC – compact, high-brightness polarized electron source.
Funded by LDRD

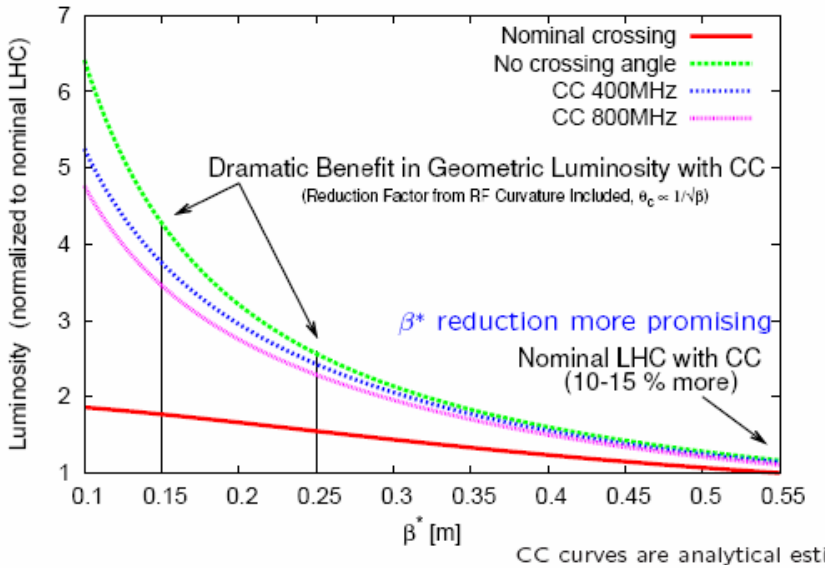






J. Kewisch, T. Rao, D. Pate, Q. Wu

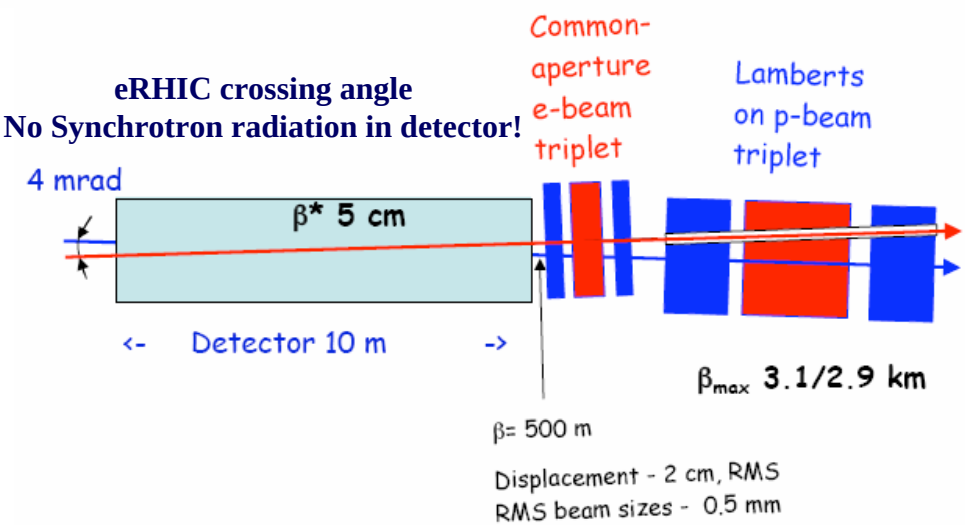
Crab Cavity R&D

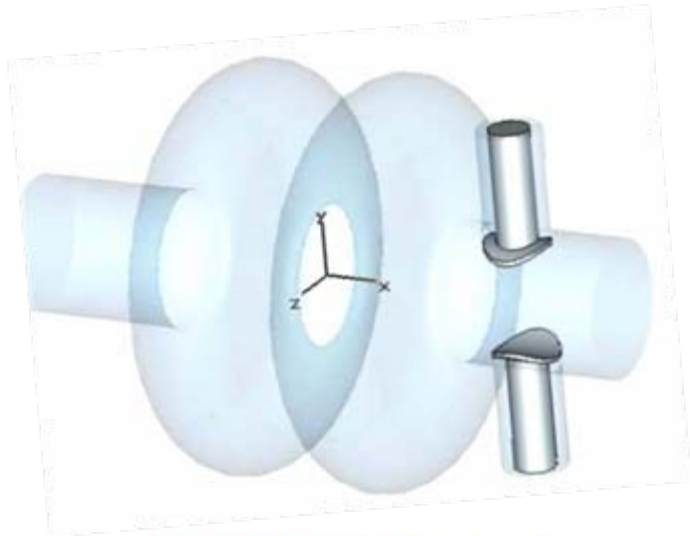


CC curves are analytical estimates

LARP Project funding
Potential luminosity upgrade for LHC
Potential luminosity increase for eRHIC

eRHIC crossing angle
No Synchrotron radiation in detector!

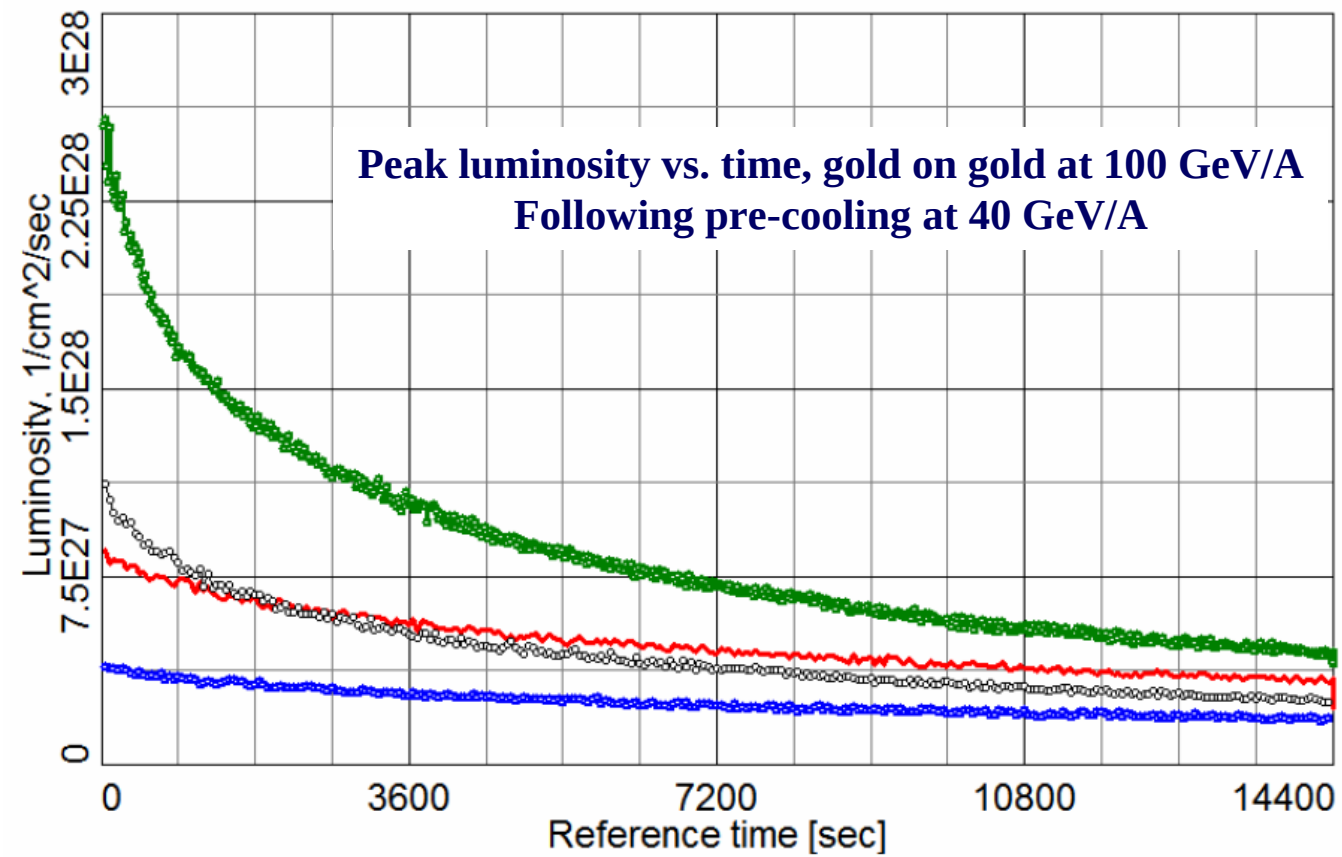




The status of electron cooling of RHIC

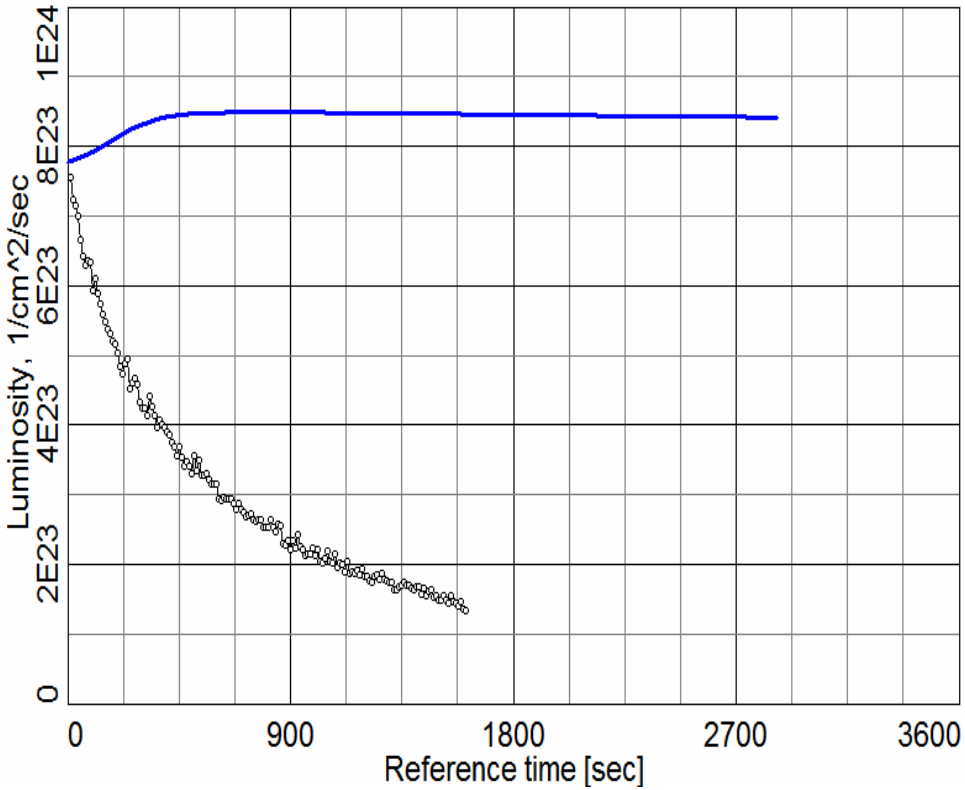
- Detailed studies of high-energy electron cooling for RHIC has been completed. Significant advances to the state-of-the-art were made.
- The advances in stochastic cooling and the 56 MHz cavity limit the possible gain from high-energy electron cooling of RHIC.
- Low-energy electron cooling and pre-cooling of RHIC beams are being pursued.
- Coherent Electron Cooling (Derbenev, Litvinenko) emerged as a most powerful cooling technique with dramatic results for eRHIC. This technique is now our main focus of R&D.

R&D ERL: Cool @ 40 GeV/A, collide @ 100 GeV/A



1) green – $N=1.5\times10^9$, pre-cooled to $\varepsilon_x=7.5$ μm (95%, normalized), $\beta^*=0.5$;
2) gray – $N=1.0\times10^9$, pre-cooled to $\varepsilon_x=7.5$ μm (95%, normalized), $\beta^*=0.5$;
3) red – $N=1.5\times10^9$, $\varepsilon_x=15$ μm (95%, normalized), $\beta^*=0.8$;
4) blue – $N=1\times10^9$, $\varepsilon_x=15$ μm (95%, normalized), $\beta^*=0.8$.

Low Energy RHIC Electron Cooling

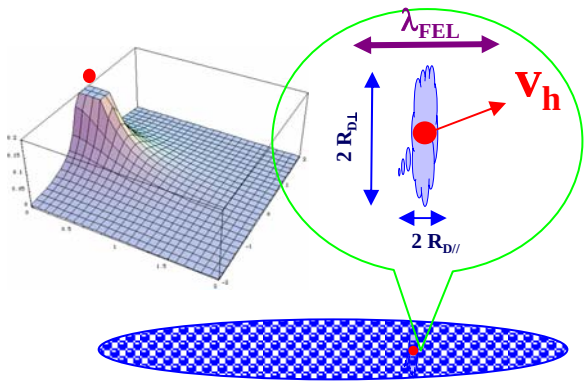


Simulation of "ideal" (no machine nonlinearities were included, just IBS and beam loss from RF bucket) luminosity with (blue line) and without (black dots) electron cooling at γ=2.7 for 56 bunches.

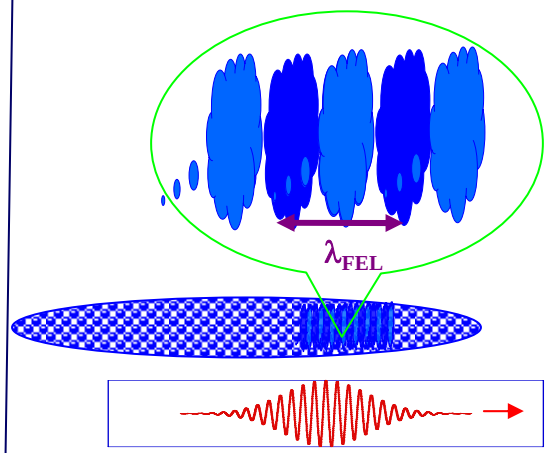
This cooling can be done in a variety Of ways, including the use of the electron gun of the R&D ERL.

Coherent electron cooling (γ>>1)

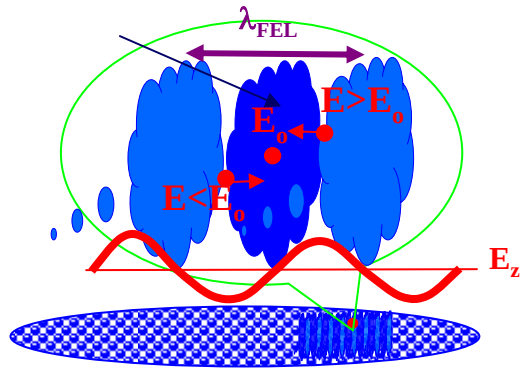
The ion imprints its position on the electrons



The FEL interaction leads to an amplified charge signal



The amplified charge "kicks" the ion



Longitudinal dispersion for hadrons

Hadrons

Modulator

Kicker

Electrons

FEL amplifier

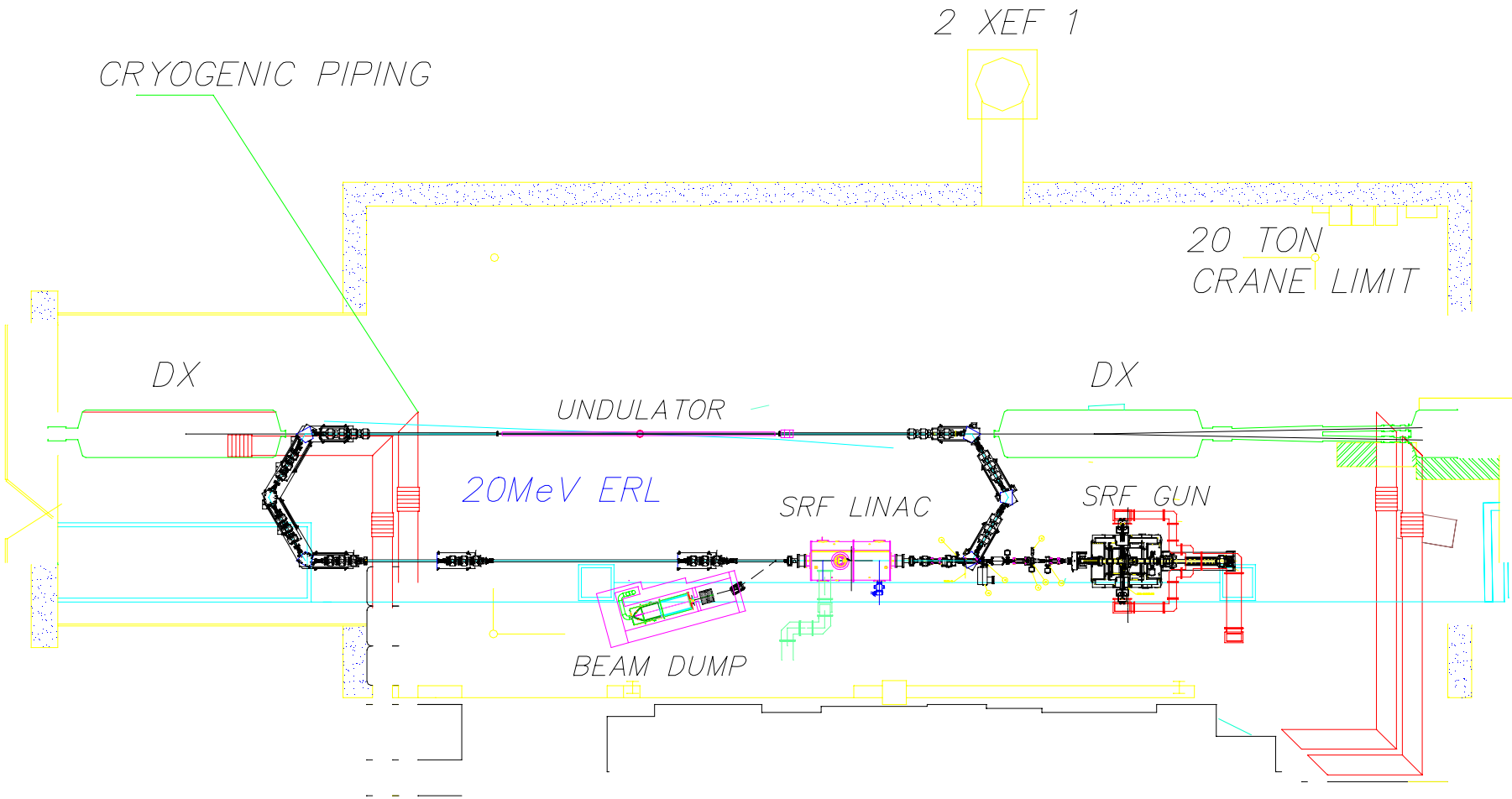
Modulator: a quarter to a half of plasma oscillation. Simulations @ Tech-X, G. Wang, M. Blaskiewicz model

Amplifier of the e-beam modulation via FEL with gain G_{FEL}~10^2-10^3

Kicker: less then a quarter of plasma oscillation. Other ions and electrons lead to noise to average out.

The Coherent Electron Cooling with FEL method owes its feasibility to the high-brightness, high-current ERL as well as the development of FEL amplifier science.

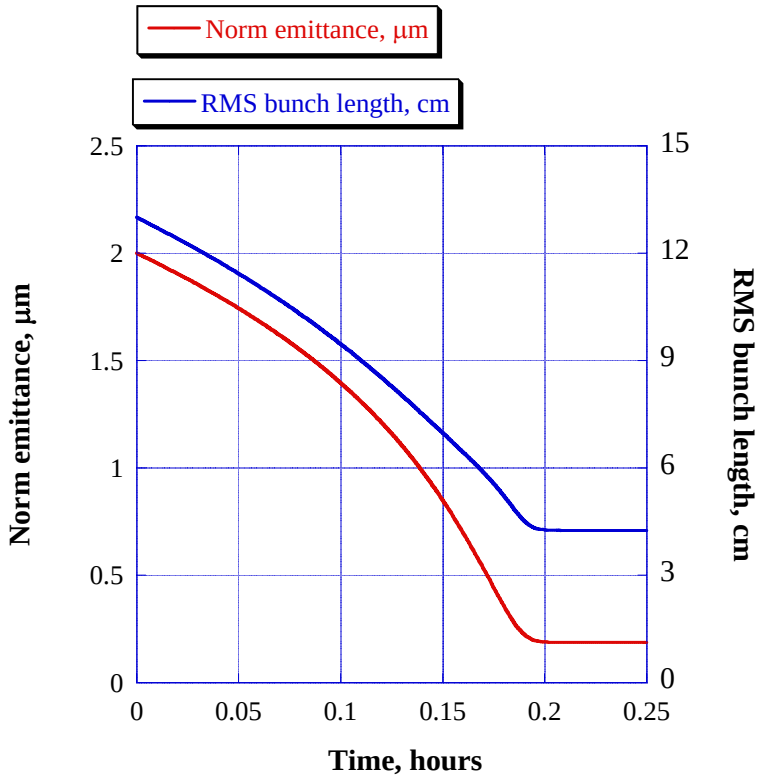
CEC POP Experiment in IR2, 40 GeV/A gold ions



Coherent Electron Cooling

- Like electron cooling, the cooling speed improves as the beam cools down, keeping pace with IBS.
- Unlike electron cooling, the CEC cooling decrement does not depend on hadron energy!
- Variable ratio of longitudinal and transverse cooling possible.
- Cooling speed uniform across beam cross section, thus no extreme changes in distribution.

$$\left\langle \zeta_{CeC} \right\rangle = \zeta \frac{\sigma_{\tau,e}}{\sigma_{\tau,h}} = \kappa \cdot \frac{8G}{\pi} \cdot \frac{Z^2}{A} \cdot \frac{r_p \cdot \sigma_{\tau,e}}{\varepsilon_{n,h}\left(\sigma_\varepsilon \cdot \sigma_{\tau,h}\right)}; \ \kappa \sim 1$$



Cooling 325 GeV protons in eRHIC:
Modulator 15 m, FEL 12.5 m, kicker 5 m, electrons 100 A peak, wiggler period 5 cm, FEL gain 200 at 0.5 μ

Summary

- The missions and activities of the Superconducting Accelerator and Electron Cooling Group continue to grow and diversify.
- The projects of the group cover the whole range from immediate luminosity upgrades to R&D towards a future Electron Ion Collider.
- The R&D carried out by the group is cutting edge accelerator science, with applications in various areas.
- The activities of the group are funded by a large variety of sources, including besides DOE NP also DOE HEP, BNL funding sources (LDRD, patent revenue), ONR and SBIRs.